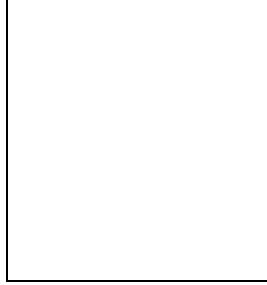


DIS DATA AND THE PROBLEM OF SATURATION IN SMALL- x PHYSICS.A. CAPELLA^a, E.G. FERREIRO^b, A.B. KAIDALOV^c AND C.A. SALGADO^a^a*Laboratoire de Physique Théorique, U. de Paris XI, Bâtiment 210, F-91405 Orsay Cedex, France.*^b*Dep. de Física de Partículas, U. de Santiago de Compostela, E-15706 Santiago de Compostela, Spain.*^c*ITEP, B. Cheremushkinskaya ulitsa 25, 117259 Moscow, Russia.*

New experimental data from HERA explore the region of very small x and small and moderate Q^2 . We study the role of unitarity corrections in the description of these data. For that, we propose a model separating the small and large components of the $q\bar{q}$ fluctuation. This model gives a unified description of total and diffractive production in γ^*p interactions. In this model unitarity corrections are controlled by diffraction data.

One of the main experimental facts discovered at HERA is the fast growth of parton densities as energy increases, or equivalently as $x \rightarrow 0$. Taking $\sigma^{tot} \sim s^{\alpha(0)-1}$ ($F_2 \sim x^{-\alpha(0)+1}$) values of $\Delta \equiv \alpha(0) - 1$ in the range $0.1 \div 0.5$ have been reported. These values depend on the virtuality Q^2 ^a. A behavior like this would violate unitarity given by the Froissart bound ($\sigma \lesssim (\log s)^2$ as $s \rightarrow \infty$). Unitarity is restored in Regge models by allowing for multiple exchange of Regge trajectories. We present a model² which takes into account all multiple pomeron exchanges in eikonal approximation. These unitarity corrections are controlled by diffraction. In parton language, the high density of partons (mainly gluons) at small values of x makes the gluon fusion to become important, stopping the increase of the density. In any case, unitarity corrections are given by non-linear terms, the importance of which grows with energy. These non-linearities would eventually give a saturation of partonic densities³ at small enough values of x (the actual value depending, in general, on the value of Q^2) and different models try to understand the onset of this effects^{2,4}. In experiments with nuclei, parton densities are a factor $\sim A^{1/3}$ larger, so, saturation starts at larger values of x than in experiments with nucleons⁵.

^aIn Regge phenomenology $\alpha(0)$ is the intercept of the exchanged object, a pomeron at high energy, this is why two different pomerons, a hard and a soft one, have been proposed in order to explain this feature. Unitarity effects, however, make also Δ_{eff} to depend on Q^2 and x , as in our case¹.

1 The model.

The description of the lp collision in the laboratory frame is very appropriate to include unitarity effects. In this frame, the virtual photon γ^* emitted by the l fluctuates into a $q\bar{q}$ pair. This system suffers then multiple interactions with the proton. We propose a separation in two components depending on the transverse size r of the $q\bar{q}$. A small component S for $r < r_0$, where the pQCD result, $\sigma^{q\bar{q}p} \sim r^2$, is used, and a large L component, for $r > r_0$, described by Regge phenomenology. r_0 has been taken as a free parameter and its value turned out to be small, $r_0=0.2$ fm. Unitarity corrections to both components are given by multiple scattering in a generalized eikonal approach which includes triple pomeron interaction. The total γ^*p cross section is $\sigma^{tot} = \sigma_S^{tot} + \sigma_L^{tot}$ with

$$\sigma_S^{tot} = 4 \int d^2b \int_0^{r_0} d^2r \int dz |\psi(r, z)|^2 \frac{1 - \exp(-C\chi_S(x, Q^2, b, r))}{2C}, \quad (1)$$

$$\sigma_L^{tot} = 4g_L^2(Q^2) \int d^2b \frac{1 - \exp(-C\chi_L(x, Q^2, b))}{2C}, \quad (2)$$

where $|\psi(r, z)|^2$ and $g_L^2(Q^2)$ describe the $\gamma^* - q\bar{q}$ coupling (see ref. ²), C is a parameter to take into account the dissociation of the proton. The eikonals are

$$\chi_S(r, b, s, Q^2) = \frac{\chi_{S0}(r, b, s, Q^2)}{1 + a \chi_3(b, s, Q^2)}, \quad (3)$$

$$\chi_L(s, b, Q^2) = \frac{\chi_{L0}^P(b, \xi)}{1 + a \chi_3(s, b, Q^2)} + \chi_{L0}^f(b, \xi) \quad . \quad (4)$$

Where

$$\chi_{S(L)0}^k(b, \xi) = \frac{C_{S(L)}^k}{\lambda_{0k}^{S(L)}(\xi)} \exp\left(\Delta_k \xi - \frac{b^2}{4\lambda_{0k}^{S(L)}(\xi)}\right) \quad , \quad (5)$$

and

$$\Delta_k = \alpha_k(0) - 1 \quad , \quad \xi = \ell n \frac{s + Q^2}{s_0 + Q^2} \quad , \quad \lambda_{0k}^{S(L)} = R_{0kS(L)}^2 + \alpha'_k \xi \quad . \quad (6)$$

With $a = 0$, the model described above is a standard quasi-eikonal with Born terms given by pomeron plus f exchanges ($k = P, f$). Note that the contribution of the f -exchange to the S component is very small² and has been neglected. In eq. (5), the constants C_S^P and C_L^f determine respectively the residues of the pomeron and f -reggeon exchanges in the $q\bar{q}$ -proton interaction. In contrast, due to the pQCD result $\sigma^{q\bar{q}p} \sim r^2$ mentioned above, the corresponding coupling C_S^P is taken to be proportional to r^2 (see the discussion in section 2).

In eqs. (3) and (4), $a = g_{pp}^P(0)r_{PPP}(0)/16\pi$, where $g_{pp}^P(0)$ and $r_{PPP}(0)$ are the proton-pomeron coupling and the triple pomeron coupling respectively, both at $t = 0$. The expression of χ_3 can be found in². The denominator in eqs. (3) and (4) correspond to a resummation of triple pomeron branchings (the so-called fan diagrams). The values of the parameters can be found in ref. ². It is important that we have fixed the pomeron intercept $\alpha_P=1.2$, and are the unitarity corrections which make the effective intercept to depend on x and Q^2 .

The diffraction cross section is given by non-linear terms $\chi_{S,L}^n$, $n > 1$ and $\chi_{S,L}^i \chi_3^j$, $i, j > 0$ in the expansion of (1) and (2). We call the former S and L contributions to diffraction and the latest PPP contributions: $\sigma_{\gamma^*p}^{(diff)} = \sigma_S^{diff} + \sigma_L^{diff} + \sigma_{PPP}$. The expressions of these components can be found in².

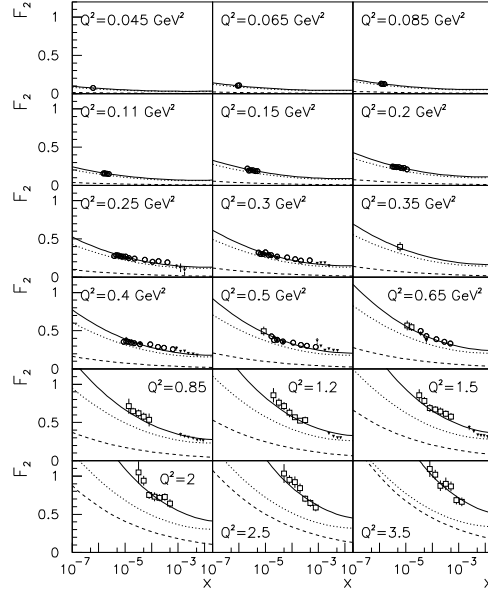


Figure 1: $F_2(x, Q^2)$ as a function of x for different values of Q^2 compared with experimental data from H1 1995⁶ (open squares), ZEUS 1995⁷ (black circles), E665⁸ (black triangles) and ZEUS BPT97⁹ (open circles). Dotted curve corresponds to the L contribution, dashed one to the S contribution and solid one to the total $F_2(x, Q^2)$ given by the model.

2 Results and conclusions.

In Fig. 1 we compare our results with $F_2(x, Q^2) = Q^2/(4\pi^2\alpha_{em})\sigma^{tot}(x, Q^2)$ data for different values of Q^2 from 0.045 GeV² to 3.5 GeV². It is clear from the figure that the S component is negligible for small values of Q^2 and would eventually become bigger than L one at large values of Q^2 . In Fig. 2 comparison with diffraction is done for $x_P F_2^{D(3)} = Q^2/(4\pi^2\alpha_{em})\sigma^{diff}$ for different values of Q^2 and with diffractive photoproduction cross section.

In summary, we have developed a two components model that takes into account unitarity corrections by multiple scattering of the γ^* in a generalized eikonal approach which includes triple pomeron. This unitarity corrections are controlled by the ratio $\sigma^{diff}/\sigma^{tot}$, so, we have performed a joint fit of total and diffractive data in lepton-proton collisions. The unitarity corrections for the two components have different behaviors. At moderate values of Q^2 , $r^2 \sim 1/Q^2$ and $\chi_S \sim 1/Q^2$, while χ_L is Q^2 independent. This makes unitarity corrections more important for the L than for the S component (in agreement with the fact that L part contribution to diffraction is larger than S one). In fact, the mean number of collisions is only ~ 1.1 for the S part at present energies, so the contribution to unitarity corrections of the terms in powers of $1/Q^2$ (higher twist terms) is less than 5% at $Q^2 \lesssim 4$ GeV². This results can be extended to larger values of Q^2 by taking into account QCD evolution with initial conditions given by the model¹². Finally, saturation will be reached when eq. (1) and (2) get the $(\log s)^2$ behavior. This will require energies much larger than present ones¹³.

Acknowledgments

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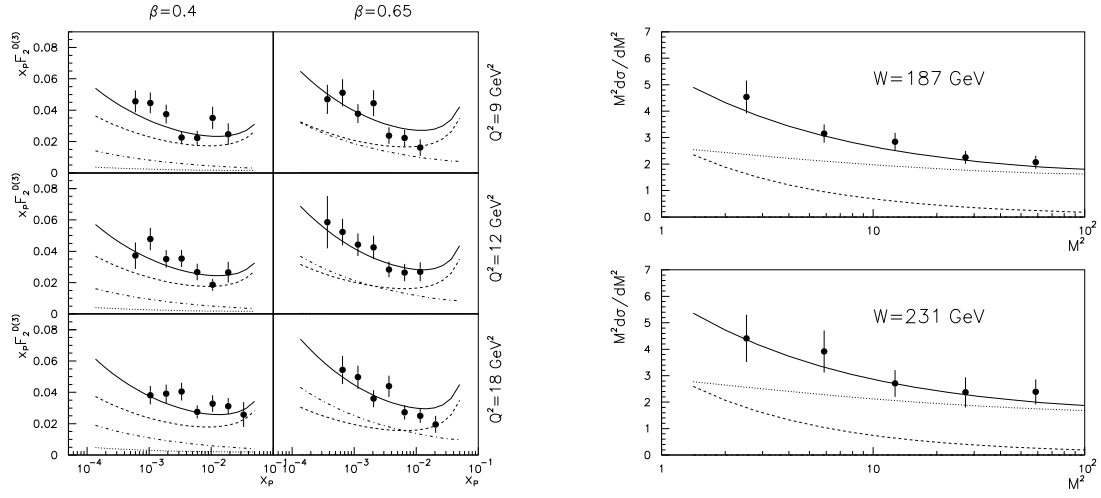


Figure 2: Diffraction: $x_P F_{2D}^{(3)}$ as a function of x_P for different Q^2 and β (left) data are from ¹⁰ and diffractive photoproduction cross-section for $W=187$ and 231 GeV as a function of M^2 from ¹¹ (right) compared with the model (solid lines). The curves correspond to PPP (dotted), L (dashed) and S (dotted-dashed) contributions.

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